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BUREAU OF WATER AND WASTEWATER

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High Level Collection System Evaluation and Sewershed Plan

Project 1028

I&I Evaluation

December 18, 2009

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Baltimore High Level Sewershed
Infiltration and Inflow (I&I) Evaluation Report
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List of Acronyms

Acronym	Definition
ADDF	Average Dry Day Flow
BCDC	Baltimore City Detention Center
BI	Base Infiltration
DST	Eastern Daylight Savings Time
EST	Eastern Standard Time
GIS	Geographic Information System
GPS	Global Positioning System
GRI	Gwynn's Run Interceptor
HLI	High Level Interceptor
HLSS	High Level Sewershed
I/I	Inflow and Infiltration
IDM	Inch-diameter-mile
JF	Jones Falls
L.F	Linear Foot
MDF	Minimum Daily Flow
MGD	Million Gallon per Day
PVC	Poly Vinyl Chloride
R	Capture Coefficient
RDII	Rainfall Derived Inflow and Infiltration
RTU	Remote Terminal Unit
SQL	Structured Query Language
SSO	Sanitary Sewer Overflow
WFP	Water Filtration Plant
WWP	Waste Water Production
WWTP	Waste Water Treatment Plant

EXECUTIVE SUMMARY

As part of the Baltimore City project No. 1028, the High Level Sewershed (HLSS) team has conducted an analysis of inflow and infiltration (I/I) into the City's sewage collection system within HLSS. This report outlines the results of the I/I analysis.

To support this I/I analysis and calibration of the dynamic hydraulic model, the City completed a comprehensive City-wide monitoring program. This program consisted of over 350 flow monitors system-wide from May 9, 2006 to May 18, 2007, with 40 metering locations within HLSS and 5 locations at the boundaries between HLSS and other neighboring sewersheds. Some locations deemed long term meters remained after May 18, 2007. In addition to the flow monitors, 20 rain gauges were installed throughout the City and in the surrounding Baltimore County drainage areas.

The team used Sliicer, software developed by ADS Environmental Services Inc., to analyze I/I severity in HLSS using rainfall and flow data. A total of 29 rain events, termed "global storms", during the metering period met the criteria for a storm event defined by the City's criteria. An analytical technique for evaluating and comparing the I/I of sewershed basins under widely varying rain events is the flow versus rainfall (Q vs. i) diagram. The slope of the regression line on the Q vs. i diagram was used to derive the capture coefficient (R), which expresses the fraction of rainfall that enters a sewage collection system during wet weather.

In HLSS, more than 16 flow meters were installed in series from the upstream end of Gwynn's Run Interceptor (GRI) to the downstream end of High Level Interceptor (HLI). Flow imbalances observed at 11 of these 16 meters made the analytical results of dry and wet weather flow conditions unreliable. The HLSS team excluded these metered basins from both dry and wet weather flow analyses used in subsequent project 1028 tasks, and aggregated the basins to overcome the imbalance issues. However the results of the individual BI determinations are reported here for consistency with other sewershed study reports.

Based on the basins with reliable data, the normalized BI exceeded 4,000 gal/IDM for 15 flow metering basins and exceeded 6,000 gal/IDM for nine basins. Geographically, the BI rate was very high (i.e., greater than 4,000 gal/IDM) for the upper GRI basins located north of the Ashburton WFP, and several minor tributary basins contributing to HLI near the intersection of N Martin Luther King JR Blvd and W Franklin St.

For the wet weather analysis, the normalized year-round RDII rate was calculated for each flow basin with reliable flow data. The year-round RDII exceeded 10 (gal / l.f. / inch of rain) for eight basins. Most of these were located in the upper GRI drainage area. The year-round RDII was between 5 and 10 (gal / l.f. / inch of rain) for 13 basins, and less than 5 (gal / l.f. / inch of rain) for only five basins. Four of the five less-severe RDII basins were located in southeast portion of the HLSS and drained directly to HLI.

The smoke testing database was utilized to count the number of detected sources for each flow basin. The smoke testing results were also used to check the dry and wet weather flow analysis. The Most numerous defect source was sewer cleanouts, considered as only a minor contributor of RDII. The major sources included catch basins, service laterals, and area drains. These non-cleanout defects exceeded one per 10,000 feet of sewer pipes in nine basins.

A review of depth-velocity scattergraph plots for the meters showed evidence of possible sanitary sewer overflows (SSOs) during monitoring at or near the meters in eight basins. Along the HLI, HL07, HL09, and potentially HL18 exhibited maximum surcharge depths that exceeded or nearly exceeded the manhole depths. A known SSO along HLI was the recurring overflow near the Baltimore City Detention Center (BCDC). The nearest meter near HL08A was approximately one-thousand feet upstream of the flow meter HL08A, too distant from BCDC to document the overflows conclusively or quantitatively. A separate report was submitted by the HLSS team to describe the analyses performed on this overflow occurrence near BCDC.

Along GRI, SSO was indicated by maximum surcharge level exceeding the manhole depth at HL38. The scattergraph for HL31 exhibited an evidence of a recurring SSO at 2800 Dukeland Street. Extended flow monitoring data available at HL31 suggested that the 2800 Dukeland Street SSO may have been alleviated by SC812, after it was placed in service since February 2007.

The City recently disabled several engineered overflows along GRI. These included five locations (55, 56, 57, 130, and 131) in the vicinity of the upstream end of SC812, and two locations (106 and 107) near the downstream end of GRI. Elimination of these engineered overflows may cause future SSOs. The scattergraphs at HL32 and 33 exhibited the evidence of overflows through the remaining engineered overflows 132, 134, and 135. Alternatives for the Liberty Heights area are documented in a separate report prepared by the HLSS team.

SECTION 1

INTRODUCTION

1.1 SEWERSHED DESCRIPTION

The High-Level Sewershed (HLSS) has a drainage area of approximately 4,600 acres served by separate storm and sanitary sewers. The majority of this area is residential with a total population of 100,000 (based on the Year 2000 census data). The HLSS has about one million linear feet of sewers with pipe sizes ranging from 8-inches in diameter to rectangular pipes of width 144-inches and height 129-inches at its downstream end. This drainage area generally slopes downward from the northwest to southeast direction.

Flows from the northwest portion of this drainage area are collected by GRI which, in turn, discharges into the larger High Level Interceptor (HLI) at the southwestern corner of HLSS. The upstream end of HLI is Baltimore Street Diversion, which can divert flow from Gwynn's Falls Interceptor (GFI) into the HLI. The diversion gate is normally closed, but is opened under emergency conditions when the GFI flow may exceeds the capacity of Southwest diversion or Patapsco Waste Water Treatment Plant (WWTP). The HLI runs from west to east receiving flow contributions from HLSS in the upstream reach, and large flows from the Jones Falls and Low Level Sewersheds in the downstream reaches. The HLI becomes the Outfall Interceptor at the beginning of Outfall Sewershed and the Outfall Interceptor eventually conveys flow to the Back River WWTP for treatment and disposal to the Baltimore Harbor.

1.2 OBJECTIVES OF THE CITYWIDE FLOW MONITORING PROGRAM AND I/I STANDARDIZATION

The City had established two main objectives for the Comprehensive Flow Monitoring Program:

1. Collect accurate rainfall and flow data – the program would accomplish this goal by requiring:
    - The use of latest metering technology and Doppler radar rainfall measurements;
    - Daily data collection using wireless communication, which identifies equipment malfunctions sooner and, therefore, maximizes rainfall and flow data availability; and
    - Multi-tier data processing and data quality assurance by the service providers and the City.
2. Standardize I&I evaluation – this goal would be accomplished by:

- Establishment of standard I&I evaluation parameters and definitions for the use of all Sewershed Consultants; and
- Requirement for all Sewershed Consultants to use a standard I&I evaluation software (Sliicer.com®, a registered mark of ADS Corporation).

1.3 RECENTLY COMPLETED SANITARY SEWER PROJECTS

Three sewer construction and rehabilitation projects, required under Paragraph 8 of the CD, were completed before early 2007. Project SC812 caused diversion of GRI flows away from some of the meters, and changes in the upstream/downstream relationship of the flow basins during the middle of the flow monitoring period, making results of certain I/I analyses unreliable. A water contract (WC) project, that will have an impact on the HLSS sewer system, is ongoing in this sewershed. Table 1-1 shows the summary of these projects and Figure 1-1 shows the project locations.

Table 1-1 Recently Completed or Ongoing Projects in the High Level Sewershed

Contract No.	Description	Completion Date	SSO Eliminated
SC812	Install 9,000 LF of 30-inch relief sewer parallel to Gwynn's Run Interceptor	February 2007	106,107, and 130
SC807	Rehabilitate 22,000 LF of 8- to 30-inch pipe	March 2003	55,56,57,60,63,126,127,128, and 131
SC831	Rehabilitate 12,000 LF of 8- and 10-inch pipe	December 2006	N/A
WC1143	Wash Water Lake rehabilitation	On going	N/A

- **SC 812** is a relief pipe construction project to alleviate overflows that had periodically occurred near 2800 Dukeland Street, and has been in service since February 2007. It is a 30-inch relief line which diverts flow from the upstream portion of GRI and brings the entire flow back into GRI at Evergreen and Franklin Streets. The relieved portion of GRI takes backwash water flow from Ashburton Water Filtration Plant (WFP) through the Wash Water Lake and local sanitary flows draining to the downstream portion of GRI.

- **SC 807** is a sewer rehabilitation and relining project to eliminate a number of engineered overflows in the upper portion of HLSS draining upstream of the GRI. Over 20,000 LF of sewer including the upstream portion of GRI was relined. The project was completed in March 2003.

- **SC 831** is a sewer inspection and relining project to rehabilitate the 8 and 10-inch sewers in upper portion of the HLSS. Approximately 12,000 LF of 8- and 10-inch sewers were relined. The project was completed in December 2006.

- **WC 1143** is a Wash Water Lake rehabilitation project, which is ongoing as of January 2009. This water contract project will affect the hydraulic conditions downstream of the GRI. When the project is done, backwash water from Ashburton WFP will be retained in the 2-acre Wash Water Lake for an unknown period of time and discharged into the GRI through a modular valve control. The maximum design discharge is 5 MGD.

There are three other projects that can affect the High Level Interceptor (SC 779, SC 800, and SC 833), which were recently completed and currently services the Jones Falls Sewershed.

- **SC 779** is a sewer construction project intended to enhance the conveyance capacity of the downstream portion of Jones Falls Force Main. This sewer is 42-inches and 1,500 LF long that follows Broadway Street from Oliver Street to Gay Street and connects to the 100-inch HLI. SC 779 has been in service since 2004.

- **SC 800** is a project to upgrade the existing Jones Falls Force Main to handle increased flow from the rehabilitated Jones Falls Pump Station and the additional flows from the Stony Run pumping station.

- **SC 833** is another relief sewer project servicing the Jones Falls Sewershed. SC 833 is also known as the Greenmount Interceptor and is comprised of about 7,300 LF of pipe ranging in size from 36 to 42-inches. The Greenmount Interceptor was completed in May 2008 from Bonaparte Avenue to the 100-inch HLI on Eager Street and has been in service since May 27, 2008.

Further details on projects SC 779, 800 and 833 can be found in the I&I Evaluation Report of the Jones Falls Sewershed.

1.4 BASES MANUAL REQUIREMENTS

The Baltimore Sewer Evaluation Standards Manual (BaSES), developed by the City to support the sewershed studies, establishes standard guidelines for I&I analyses and outlines additional requirements for tasks such as hydraulic model calibration.

1.5 FLOW BASIN AGGREGATION

As prescribed in the Consent Decree, it is required to determine I/I rate in each sewershed, in which I/I rate refers to the dry weather BI and wet weather RDII. The I/I rates can be calculated using flow rate generated by each sewershed (i.e., flow basin), so called the net flow rate. For a flow basin which has one or more upstream subsewersheds, the net flow rate is the gross flow rate subtracted by the total gross flow rates from all immediate upstream flow meters. There are several cases where the net flow evaluation can become difficult due to reasons such as: (1) there is irregular inflow from upstream and (2) the net flow is much smaller than gross flow.

For reason (1), the Ashburton Water Filtration Plant (WFP) was the only major irregular inflow source in HLSS during the primary flow monitoring period. The Ashburton WFP discharged filter backwash water into GRI with multiple pumps. Their irregular discharges into GRI made the I/I rate evaluation difficult for several downstream flow meters including HL25, 26, 28, and TSHL03.

For reason (2), a major factor to determine the ratio of net flow to the gross flow was the ratio of net flow basin area to the gross flow basin area since each flow basin represented the contributing area to net flows. It is suggested that the net flow rate would need to be greater than 20% of the gross to determine I/I rate accurately. The net/gross area ratio for the HLSS is shown in Figure 1-2. Flow basin is colored in red if the net area was less than 10% and colored in orange if the net area was in the range of 10 – 20% of the gross area. For HL26 and all the downstream flow basins along GRI and HLI are colored in red, which implies that determining the I/I rate was very difficult for the flow basins: HL07, 08, 09, 14, 18, 19, 25, 26, and TSHL03.

In order to deal with the limitations in determining I/I rates for the interceptor basins, the HLSS team decided to aggregate these basins and a few non-interceptor basins where the flow data quality was questionable so that the I/I rate could be determined accurately for a larger area. This aggregation process is explained further for dry weather and wet weather flow analyses separately in the following chapters.

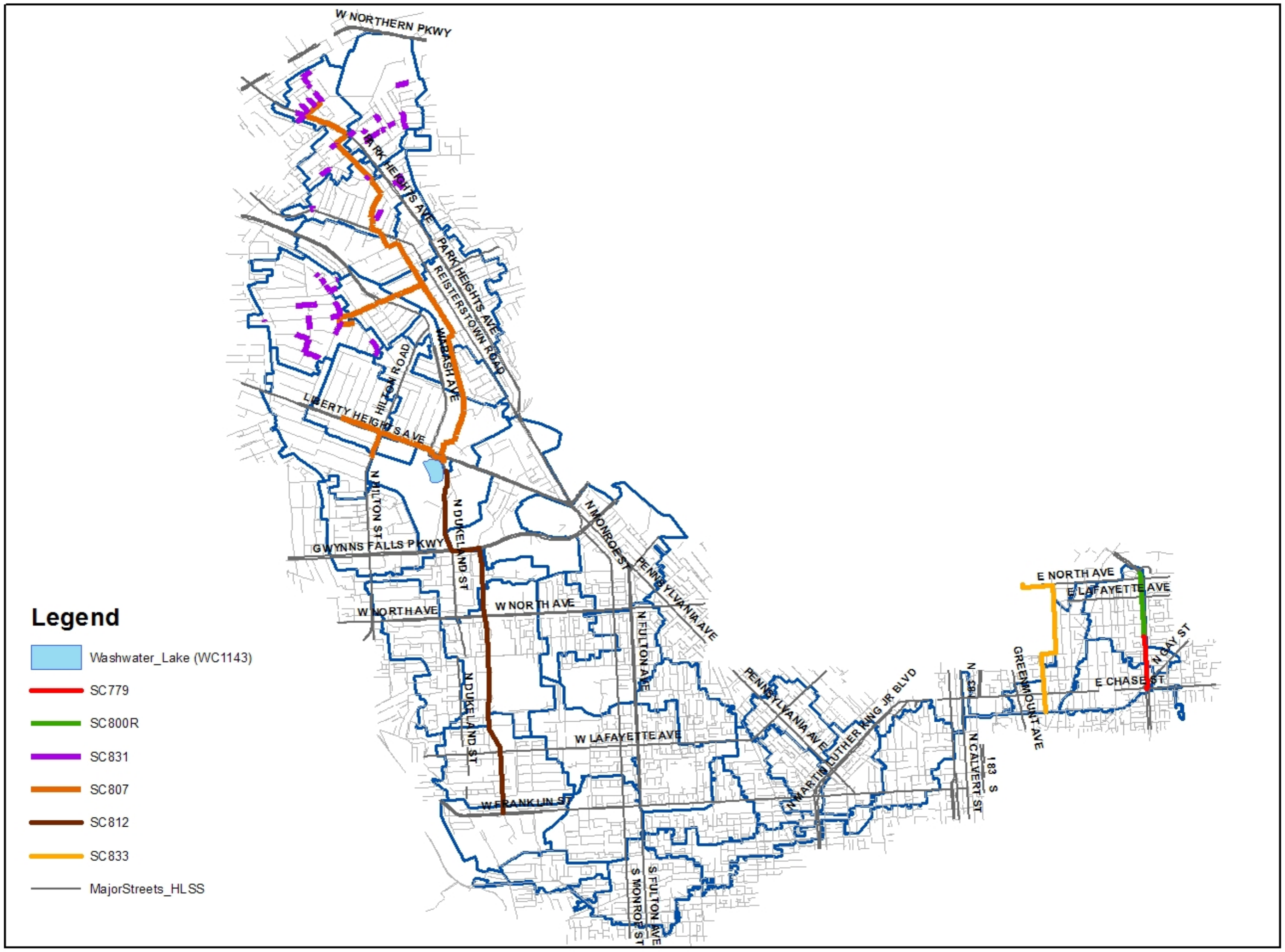

Figure 1-1 Recently completed sanitary projects in the High Level Sewershed

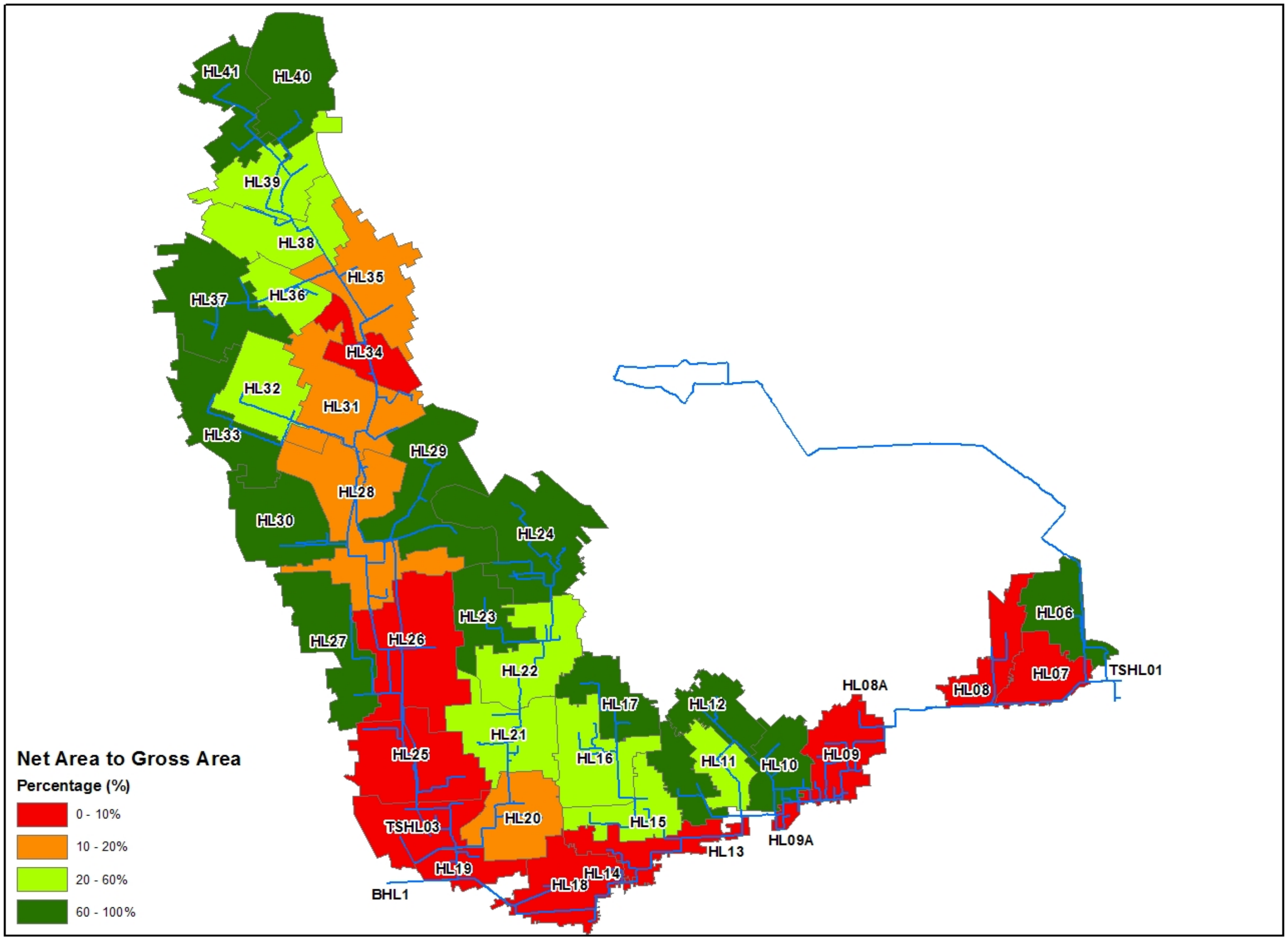

Figure 1-2 Ratio of net to gross subsewershed areas in HLSS

SECTION 2

FLOW MONITORING PROGRAM

2.1 OVERALL DESCRIPTION

In order to fully understand and characterize the dynamic hydraulic conditions in the sewage collection system, the City completed a comprehensive City-wide flow monitoring program. This program consisted of flow meters installed in the City's collection system and rain gauges installed throughout the City and surrounding Baltimore County drainage areas. The flow monitors measured sewage depth and velocity in the target sewer at 5-minute intervals. The City-wide monitoring program included over 350 flow monitors; 40 of those flow monitors were installed within HLSS and five of them were installed at boundaries with the other sewersheds. Primarily, the flow monitoring was conducted from May 9, 2006 to May 18, 2007. Flow metering is being continuously conducted at some locations as part of the long term system-wide flow monitoring.

In addition to these 45 locations, six temporary flow meters were installed in the HLSS subsequent to the global calibration period (May 2006 to May 2007). Four of these meters were installed to evaluate the effectiveness of the newly constructed SC812 relief sewer. These were installed on April 8, 2008 at the upstream and downstream ends of SC 812 and the relieved portion of GRI. They were in service until January 2009. The other two meters were installed at the upstream and downstream ends of the High Level Siphon to study the local hydraulic conditions (i.e., capacity, silt accumulation and head loss) and to determine if the siphon had any capacity limitations. These meters were in service from June 2008 to January 2009.

Table 2-1 shows the list of meters, purpose, and installation history and Figure 2-1 shows the locations of flow meters and rain gauges. Figure 2-2 depicts a schematic of the monitoring plan.

Twenty rain gauges were installed in the drainage areas located within Baltimore City and surrounding Baltimore County. All 20 rain gauges were utilized in conjunction with the generated radar rainfall to support the I/I analysis.

2.2 SUMMARY DESCRIPTION OF THE METERING NETWORK WITHIN THE SEWERSHED

The 45 flow-monitoring sites within HLSS were chosen based on various data needs. A majority of those (36 sites) were installed for I/I evaluation and model calibration. Four sites (HL08A, HL09A, TSHL03, and TSHL01) were installed only to support model calibration and the remaining five (BHL1, JFPS, JFOUT, OUT05, and OUT06) were installed as boundary meters. Using the City's Geographical Information System (GIS) the metering sites for I/I evaluation were chosen at a meter density of approximately one site for every 25,000 linear feet of sewer pipes.

2.3 FLOW METERING

2.3.1 Equipment Description

The City conducted the City-wide Flow Monitoring program through services of three qualified contractors under sewer contracts 995A, 995R and 995S. Depth-velocity meters were used in the city-wide monitoring program, which were designed to calculate flow based on measured depths and velocities in sanitary sewer pipes under both free-flow and surcharged conditions. The primary depth sensor is ultrasonic with a resolution to the nearest 0.01 foot. The meters have redundancy for level measurements, in the form of a pressure sensor, with an accuracy of +/- 0.25 percent of the full scale. The project specifications required that the primary velocity sensor use Doppler technology, which is capable of measuring flow velocities in the range between -5 to +15 feet per second. The sensors were securely attached to the pipe by strapping with metal bands or anchoring hardware designed specifically for that purpose.

2.3.2 Installation

Every metering location was verified by a flow monitoring contractor by performing a thorough site investigation from within a manhole chamber. Local hydraulic conditions at each site dictated the metering equipment selection and optimal sensor placement. If a location was deemed unsuitable for flow monitoring, the contractor was required to coordinate with the City and to investigate up to two alternate sites for consideration. The contractor also checked for debris in the manhole that could impact data quality. For each location, the contractor prepared and submitted an electronic site investigation report, which included a general site location map, a sketch of the installation, the physical characteristics (diameter or other measurements as necessary to define the pipe cross-section, material, etc.) of the sewer pipe in which the sensors would be installed, manhole depth, and other comments deemed pertinent by the contractor. In addition, survey-grade GPS (Maryland State Plane: +/- 0.5 inch) coordinates, pipe inverts and rim elevations; and three digital images of the site were recorded, including one image that showed the sensor installation.

The contractor was required to evaluate the level of silt and debris at each monitoring location, and to undertake sewer cleaning as necessary to ensure accuracy and reliability at each metering site. In case of odd-shaped pipes, or at sites where debris or sediment was present, the contractor developed a profile and accurately determined the cross sectional areas of the pipe at various depths. A typical flow monitor installation included the primary ultrasonic depth sensor mounted at the crown of a pipe, a redundant depth sensor mounted at the invert, and a Doppler primary velocity sensor mounted in or near the pipe invert. All flow meters and rain gauges were synchronized in time to the same clock, and programmed to collect depth and velocity data at five (5) minute intervals.

Upon installation and activation of each flow meter, the contractor took manual depth and velocity readings using an independent instrumentation to confirm that the in-situ monitor yielded data representative of actual field conditions. The field crews were required to take manual velocity readings of the cross-section (velocity profile) of flow in order to determine the pipe velocity profile.

2.4 RAINFALL MEASUREMENT

The contractor was required to measure the contribution from rainfall to all sewersheds within the City's jurisdictional boundary using a network of rain gauging stations with a minimum coverage of one (1) rain gauge station per ten (10) square miles. Also required were the data compiled by the City using Doppler radar utilizing a minimum resolution of one (1) pixel per four (4) square kilometers. In order to measure the rainfall occurring in portions of the collection system in Baltimore County, the contractor installed additional rain gauges outside the City limits.

2.4.1 Equipment Description

The equipment consisted of a data logger enabled to accept data from an industry standard rain tipping bucket. The equipment was able to measure 0.1 inches (2.5 mm) per tip of bucket. A corrosion resistant funnel collector was included with the tipping bucket assembly.

2.4.2 Installation

Most rain gauges were installed on the roofs of public schools in the City and the County, and on the facilities owned by the City's Department of Public Works (such as pump stations and treatment plants).

2.4.3 Radar Rainfall

In accordance with the consent decree requirements, the City performed Doppler radar rainfall analysis in conjunction with rain gauges installed at a resolution of one gauge for every 10 square miles. The contractor utilized a CALAMAR software platform to process each recorded rainfall event with an average total depth of greater than 0.5 inches of rain. This is a tool used to study the hydrologic impacts of precipitation through a combination of radar images and a network of rain gauges installed over a geographic area. CALAMAR uses three databases: a radar image database, a rain gauge database and a geographical database. After collecting the rain gauge network data and the radar images, CALAMAR produces a model that provides geographically accurate, integrated rainfall intensity data for any pre-defined area. The Baltimore City geographical area was divided into 1 square kilometer pixels, and for every significant rain event Doppler Radar rainfall images were generated for every pixel within the Back River and Patapsco WWTP service areas. There were a total of 29 storms, termed as global storms, recorded during the primary flow monitoring period. The dates of those storm events are listed in Table 2-2.

2.5 GROUND WATER MEASUREMENT

The contractor installed groundwater gauges at 33 flow monitoring sites designated by the City. Each groundwater gauge consisted of a conduit (preferably a clear flexible tube) of sufficient diameter to accommodate a pressure sensor. The pressure sensors were calibrated prior to installation.

2.5.1 Equipment and Installation

The groundwater gauges were connected through the manhole wall to the ground around a manhole, in the vicinity of the bench. The flexible conduit was secured to the manhole wall or steps and extended vertically to a point 6 inches below the manhole lid. The connection through the manhole consisted of a drilled hole no larger than 1.25 inches in diameter, through which a PVC or metal pipe extended to approximately 6.0 inches outside the manhole and into the ground. At the end of this PVC or metal pipe, a fine mesh was installed to let groundwater through but to keep the dirt and debris from clogging the pipe. The space between the manhole wall and PVC or metal pipe was water-tight sealed with silicon caulking or a similar material. The conduit was connected securely to the PVC or metal pipe with the proper fittings and hardware to provide a water-tight connection.

2.6 DATA COLLECTION AND PROCESSING

The contractor was required to use a host software support application program for remote wireless data collection from all flow meters, rain gauges, and the ground water gauges. The host software maintained clock synchronization with the host system's clock for all field remote terminal units (RTUs), thus insuring time interval integrity for all collected data. The City required the contractor to use a system employing client/server architecture, capable of storing all project deliverables including flow and rainfall data; equipment configurations; event logs; and site parameters into a structured query language (SQL) database. The software allowed any networked computer (with the appropriate access rights) access to the data stored in the SQL database using a common web browser (e.g., Microsoft Internet Explorer). The web module was configured to be read-only in order to protect data integrity, and it had the ability to present near-real time data. Field data measurements could be forwarded to the server immediately following collection by the field RTUs and the server could immediately post data to the web site for viewing by the authorized parties.

The contractor was required to employ trained data analysts experienced in processing and analyzing flow and rainfall data from sanitary sewer systems. Various analytical tools, such as hydrographs, scattergraphs, and flow balancing methods were used to verify the accuracy and precision of flow data. Data collection was performed remotely at least twice a week and was scheduled in a manner to allow data review by a trained data analyst within 24-hours of the data collection. The analyst assessed any maintenance or performance issues, and a crew was dispatched within 48 hours, and the issue was resolved within 72 hours from the time an issue was identified. All measurements, adjustments, and efforts undertaken during site visits were logged in an installation/maintenance log specific to that meter/gauge installation.

2.7 MONITORING PERIOD

The period of flow metering extended from May 9, 2006 to May 18, 2007. Some meters deemed long term meters have stayed in place, based on approval from the City. Table 2-1 shows the list of meters, their sub-basin, purpose, and installation history.

2.8 EQUIPMENT OPERATION, MAINTENANCE, AND UPTIME

The contractor's qualified field crews visited each monitor installation as appropriate to perform any necessary maintenance to the equipment. As stated above, field crews were dispatched within 48 hours and any operation and maintenance issue was resolved within 72 hours from the time an issue was identified. The contractor was required to collect useable flow data for a minimum of 90% of the time throughout the monitoring period, and to submit to the City an "Uptime" table each month demonstrating compliance with this uptime requirement.

The uptime requirement would be generally satisfied with actual measured data. However, in instances where a velocity measurement was not available, inferred velocity from a reliable depth measurement would not be considered downtime if the contractor demonstrated that data could be estimated with reasonable accuracy without a velocity measurement, and that the loss of velocity data was not caused by maintenance neglect. However, no velocity could be inferred for any measurement interval where: (1) a corresponding depth measurement was not obtained for that measurement interval, or (2) independent calibration measurements were not acquired for the site. The contractor was required to identify all inferred velocity data or other data derived from inferred data in all reports and deliverables.

Table 2-1 HLSS flow meter installation history			
Flow Meter	**Installation Purpose**	**Installation Date**	**Removal Date***
HL41	I/I	5/9/2006	2/29/2008
HL40	I/I	5/9/2006	2/29/2008
HL39	I/I	5/9/2006	2/29/2008
HL38	I/I	5/9/2006	2/29/2008
HL37	I/I	5/9/2006	2/29/2008
HL36	I/I	5/9/2006	2/29/2008
HL35	I/I	5/9/2006	Long Term Meter
HL34	I/I	5/9/2006	2/29/2008
HL33	I/I	5/9/2006	Long Term Meter
HL32	I/I	5/9/2006	Long Term Meter
HL31	I/I	5/9/2006	Long Term Meter
HL30	I/I	5/9/2006	5/18/2007
HL29	I/I	5/9/2006	5/18/2007
HL28	I/I	5/9/2006	5/18/2007
HL27	I/I	5/9/2006	5/18/2007
HL26	I/I	5/9/2006	5/18/2007
HL25	I/I	5/9/2006	5/18/2007
HL24	I/I	5/9/2006	5/18/2007
HL23	I/I	5/9/2006	5/18/2007
HL22	I/I	5/9/2006	5/18/2007
HL21	I/I	5/9/2006	5/18/2007
HL20	I/I	5/9/2006	Long Term Meter
TSHL03	Calibration Meter	5/9/2006	Long Term Meter
HL19	I/I	5/9/2006	5/18/2007
HL18	I/I	5/9/2006	5/18/2007
HL17	I/I	5/9/2006	5/18/2007
HL16	I/I	5/9/2006	5/18/2007
HL15	I/I	5/9/2006	5/18/2007
HL14	I/I	5/9/2006	5/18/2007
HL13	I/I	5/9/2006	5/18/2007
HL12	I/I	5/9/2006	5/18/2007
HL11	I/I	5/9/2006	5/18/2007
HL10	I/I	5/9/2006	5/18/2007
HL09A	Calibration Meter	5/9/2006	5/18/2007
HL09	I/I	5/9/2006	Long Term Meter
HL08A	Calibration Meter	5/9/2006	5/18/2007
HL08	I/I	5/9/2006	5/18/2007
HL07	I/I	5/9/2006	5/18/2007
HL06	I/I	5/9/2006	5/18/2007
TSHL01	Calibration Meter	5/9/2006	Long Term Meter
BHL1	Boundary Meter	5/9/2006	Long Term Meter
JFPS	Boundary Meter	5/9/2006	Long Term Meter
JFOUT	Boundary Meter	5/9/2006	5/18/2007
OUT05	Boundary Meter	5/9/2006	5/18/2007
OUT06	Boundary Meter	5/9/2006	Long Term Meter

*** Removal date as of February 2008**

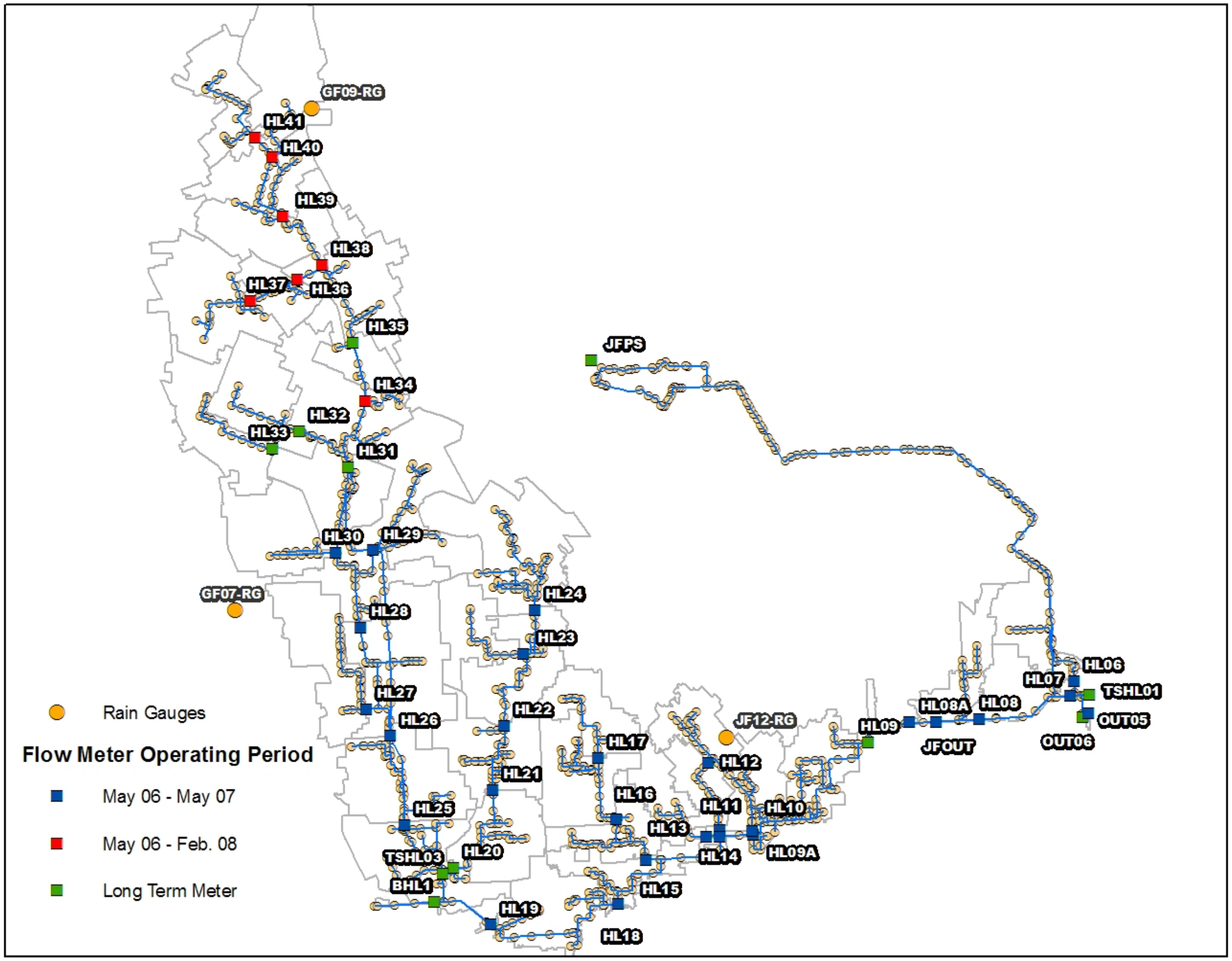

Figure 2-1 Period of system-wide flow monitoring in HLSS

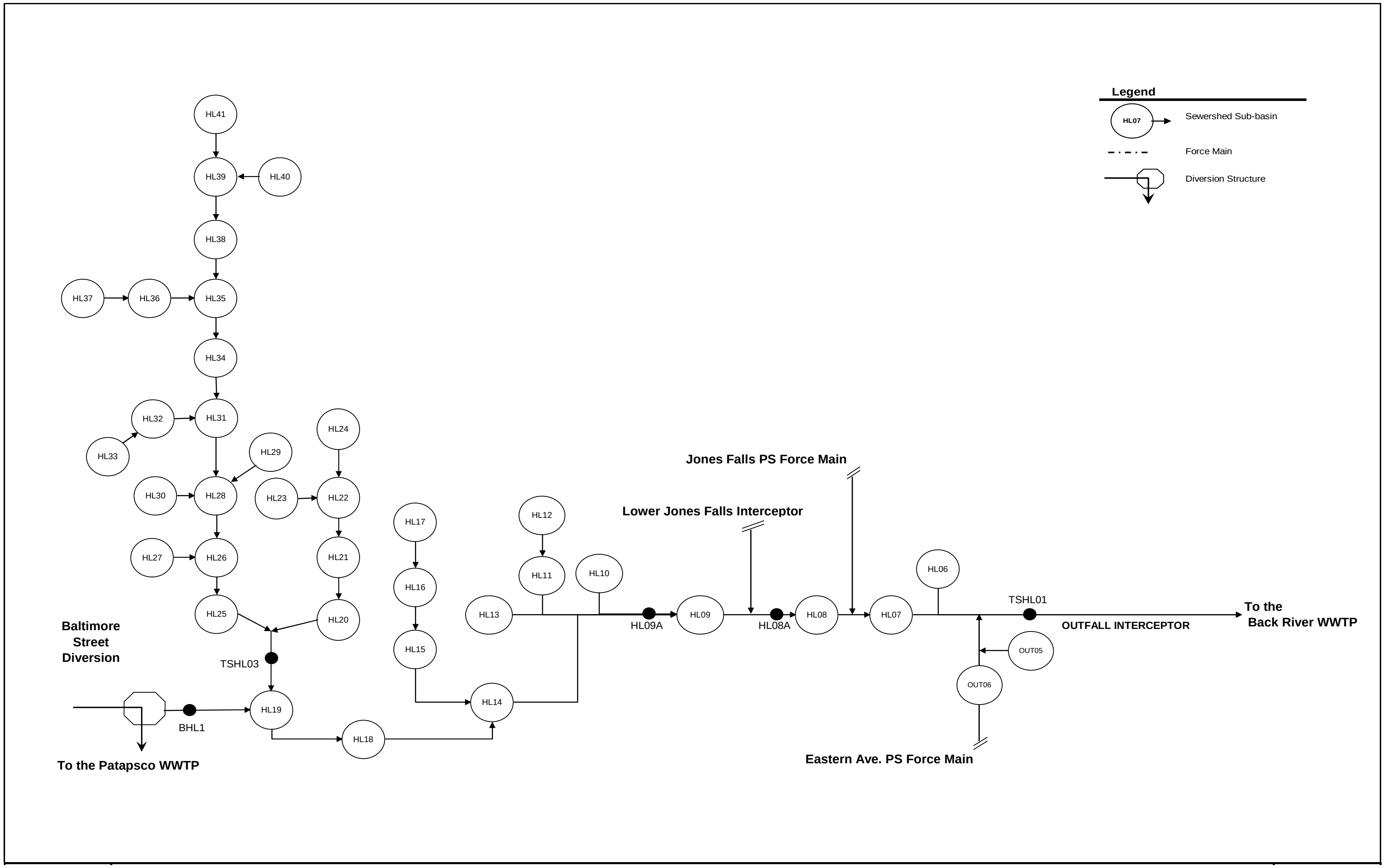

Figure 2-2 HLSS Flow Monitoring Plan Schematic

Table 2-2 Storm period and depth for global storms						
			Storm	Strom Depth (in)		
No.	Rain Start	Rain End	Period (hr)	GF07RG	GF09RG	JF12RG
1	5/11/06 12:00	5/11/06 22:00	36	1.70	2.10	1.46
2	5/14/06 23:00	5/15/06 16:00	48	1.06	0.75	0.95
3	6/2/06 19:00	6/3/06 6:00	24	0.65	1.58	0.55
4	6/19/06 14:00	6/19/06 16:00	24	0.39	0.96	0.26
5	6/24/06 13:00	6/24/06 22:00	18	0.92	0.53	0.87
6	6/25/06 4:00	6/26/06 22:00	144	6.33	6.10	5.92
7	7/5/06 11:00	7/6/06 6:00	96	2.47	1.44	3.21
8	7/22/06 14:00	7/23/06 0:00	24	0.65	1.04	0.49
9	9/1/06 6:00	9/2/06 17:00	60	2.21	2.19	2.37
10	9/5/06 2:00	9/5/06 17:00	48	1.70	1.15	2.17
11	9/14/06 1:00	9/14/06 21:00	72	1.35	1.22	1.15
12	9/28/06 17:00	9/28/06 22:00	36	0.77	0.84	0.82
13	10/5/06 20:00	10/6/06 16:00	120	1.81	1.53	1.70
14	10/17/06 7:00	10/18/06 2:00	36	1.26	1.26	1.00
15	10/19/06 20:00	10/20/06 11:00	36	0.45	0.54	0.44
16	10/27/06 15:00	10/28/06 8:00	60	1.96	2.01	1.89
17	11/7/06 20:00	11/8/06 15:00	60	1.41	1.54	1.33
18	11/16/06 8:00	11/16/06 17:00	120	2.31	1.74	2.30
19	11/22/06 11:00	11/23/06 3:00	96	0.96	0.85	0.92
20	12/22/06 12:00	12/23/06 3:00	60	1.35	1.34	1.16
21	12/25/06 12:00	12/26/06 1:00	72	0.57	0.57	0.57
22	12/31/06 16:00	1/1/07 14:00	72	1.04	0.96	0.92
23	1/7/07 17:00	1/8/07 16:00	72	0.91	0.88	0.86
24	3/1/07 18:00	3/2/07 9:00	96	1.15	1.09	0.88
25	3/15/07 16:00	3/16/07 17:00	144	2.23	2.16	2.41
26	3/23/07 13:00	3/24/07 10:00	72	0.43	0.56	0.36
27	4/4/07 3:00	4/4/07 9:00	24	0.39	0.33	0.50
28	4/11/07 21:00	4/12/07 6:00	48	0.90	0.93	0.94
29	4/14/07 19:00	4/16/07 3:00	120	2.47	2.36	2.58

SECTION 3

I&I EVALUATION

3.1 SLIICER.COM WET WEATHER ANALYSIS TOOL

The ADS/JMT Joint Venture Team (HL Team) evaluated I/I to determine the RDII of various portions of HLSS. The sewer system was divided into 37 subbasins, established as the tributary areas to the 37 wastewater flow monitors operated by the City under its SC995S contract for the City-wide Flow Monitoring program, May 2006 to May 2007. The locations of the subbasins are shown in Figure 3-1. Flow monitoring and rainfall data were warehoused by the City under the SC1015 contract and final data were furnished to the HL team online through Sli/icer.com™, an online flow data analysis website operated ADS Environmental Services. The City selected Sli/icer.com™ for use by all the sewershed consultants, as the standard engineering tool to achieve a uniform method of analysis and presentation of analytical results. Quality control of the flow data was performed by the SC1015 consultant, was outside the scope of services of the HL Team.

The HL Team performed RDII analysis using the classical EPA SSES Manual analytical approach, as required by the Consent Decree, and as embedded in the Sli/icer program:

- Calculate net hydrographs for basins with upstream meters.
- Define dry day groups: weekday and weekend, summer and winter seasons.
- Define and select non-rain days and calculate average hourly flows in each day group, to create composite dry day hydrographs.
- Identify storm events and plot event hydrographs for each, along with appropriate dry day hydrograph.
- Subtract dry day ordinates from storm hydrograph ordinates, and extract resulting RDII and rain parameters to a database. Plot the RDII curve and calculate total RDII volume under curve.
- Plot rain depth versus RDII volume for each storm, identify and remove outlier data.
- Perform linear regression of data points, define statistical parameters, and express regression as Q vs. i value (mg RDII per inch rainfall).
- Plot bar graph of RDII severities vs. subbasins, map RDII severities.

Knowing the relative RDII of each subbasin enables the HL Team to determine areas where overflow mitigation may be accomplished by I/I reduction through rehabilitation, and estimate the cost effectiveness of rehabilitation for comparison to storage/transport/treat alternatives. The reliability of the analyses are highly dependent upon the quality of the flow and rainfall monitoring data. Where flow monitoring data are incomplete, inaccurate or inconclusive, the analyses will be less conclusive but "bracketing" or sensitivity analyses may be supported.

HL Team discovered that data quality were inadequate to support the complete analysis described above for 17 out of 37 subbasins, resulting from inadequate or incomplete flow monitoring data. Inaccurate data can be caused by a variety of factors including incorrect equipment calibration, inaccurate equipment, or site or flow conditions beyond the capabilities or outside the assumption envelope of the equipment employed as well as human error.

3.2 GLOBAL SETTINGS

The Global Settings are Sliicer parameters established by the City to be used by all Sewershed Consultants. These parameters should not be changed and will provide a necessary degree of standardization among various sewershed studies pursued in the City. The global settings included:

- Average dry day flow normalized by the linear feet contained in each sub-basin.
- A 30-minute time step averaging.
- Criteria for defining dry days and which days should be excluded.
- Two seasons will be considered: Eastern Daylight Time and Eastern Standard Time.
- Threshold for a rain event to be considered in the analysis is 0.5 inches in a period of 24 hours.
- Default method for computing wastewater production will be the Stevens-Schutzbach Method.
- Rolling method will be used for rainfall peaks.
- Units used are million gallons per day (MGD) for flow rates, million gallons (MG) for volume, feet per second for velocity, and inches for flow depth.

3.3 DRY WEATHER ANALYSIS

3.3.1 Dry Day Selection

Following the criteria established in the BaSES manual, the dry days were defined in accordance with the following table:

Table 3-1 Criteria for Dry Days

Number of Prior Days	Cumulative Antecedent Rain (Inches)
1	0.1
3	0.4
5	1.0

In addition, the dry days with total flows that are 15 percent higher or lower than the average volume of all dry days were excluded from the analysis. Subsequently the dry day traces for each meter were edited to remove any outliers that might have passed through the filtering requirements. Finally, the Sliicer was used to calculate the Average Dry Day Flow (ADDF) from all the traces.

3.3.2 Dry Day Groups

The dry-day groups used were weekdays and weekends. The weekdays included Mondays through Fridays, and the weekends included Saturdays and Sundays.

3.3.3 Season Groups

The seasons used for the study were Eastern Daylight Saving Time (DST) and Eastern Standard Time (EST). Since the global calibration period included these two seasons, the groups were created to easily process the data.

3.3.4 Waste Water Production and Base Infiltration Components

The wastewater production (WWP) was calculated by subtracting the base infiltration (BI) from ADF. As required, the Stevens-Schutzbach Method was used to determine the base infiltration (BI). The Stevens-Schutzbach Method is as follows:

$$BaseInfiltration = \frac{0.4 \times MDF}{\left(1 - \left(0.6 \times \left(MDF \big/ ADF\right)\left(MDF\right)^{0.7}\right)\right)}$$

where: MDF = minimum dry flow

Table 3-2-A shows the results of the dry–weather flow analysis. There were several issues summarized in this table that are primarily attributable to flow imbalances. The cells and corresponding basin names are highlighted in gray if the:

1. Calculated WWP or BI values were negative;
2. Calculated WWP rate exceeded 35 (gallons per linear foot - gal/LF), whereas the reasonable value for WWP rate is 5 – 20 (gal/LF.); or
3. Calculated WWP was less than 50 % of winter 2007 water consumption.

As discussed earlier in this report, the net flow cannot be determined accurately for interceptor basins under the influence of highly varying boundary discharges or when the net basin area is less than the 20% of the gross area. As shown in Table 3-2-A, for 15 out of the 37 HLSS flow basins, the net area was less than 20% of the gross area, which would make the net flow calculation unreasonable.

HL28, HL26, HL25, and TSHL03 were flow meters along GRI strongly affected by the highly varying discharges from Ashburton Water Filtration Plant. HL19, 18, 14, 09, 08, and 07 were flow meters located along HLI and their net flow was less than 10% of the gross flow. In order to resolve the net flow calculation issues for the lower GRI and HLI meters, several combinations of basin aggregation were tested until the net aggregated flow was reasonably calculated. For the lower GRI meters, HL25 and TSHL03 turned out to be the most reasonable aggregation and the calculated net flow was 0.59 MGD for the 2006 summer season. For the HLI meters, all the HLI meters (i.e., HL07, 08, 09, 14, 18, and 19) were successfully aggregated and the calculated net flow was 2.29 MGD for summer 2006.

In order to resolve other local flow imbalance issues, several directly connected basins were grouped together. This process was applied to the groups of meters: HL15-16, HL32-33, HL34-35, and HL38-39. Finally, the calculated WWP values were replaced with 87% of water consumption values for basins where the calculated WWP values were less than 50% of the winter water consumption data. The 87% is average ratio of WWP to the water consumption in the HLSS.

Base Infiltration Normalization by Inch-Diameter-Miles (IDM)

Normalizing BI is important for comparing different flow basins with severe infiltration problems. A simple interpretation of infiltration rates does not always lead to right conclusions about the locations of worst problems in a collection system. For this project, the BI was normalized based on inch-diameter-miles (IDM). The IDM normalization was selected for BI because it took into account not only the length, but also the diameter of pipes in the basin. Regardless of the length, the larger the pipe diameter the more pipe surface would be exposed to leakage from groundwater. The Sliicer provides this type of BI normalization for each basin. As an example, the calculated lower GRI (HL25-TSHL03) aggregated BI using the summer 2006 flow monitoring period is 2,329; which is considered an average rate of BI.

Table 3-2-B shows the modified results of the dry weather flow analysis. Figure 3-1 shows the winter BI normalized by inch-diameter of pipes for each flow basin.

Table 3-2A Dry Weather Analysis DST - Winter 2007 - Weekdays Only													
Basin	A_{gross} (acres)	A_{net} (acres)	A_{net}/A_{gross} (%)	IDM (in-dia-mile)	ADF_{gross} Ave. Daily Flow (MGD)	ADF_{net} Ave. Daily Flow (MGD)	Q_{net}/Q_{gross} (%)	Water Consumption (MGD)	Wastewater Production WWP (MGD)	Base Infiltration BI_{net} (MGD)	Base Infiltration (BI) Severity (gpd/idm)	Base Infiltration (BI) Rate (%)	Wastewater Production (WWP) Rate (gal/l.f.)
HL06	94	94	100.0	46.0	0.43	0.43	100.0	0.15	0.13	0.30	6564	70.2	4.7
HL07	4518	81	1.8	82.1	46.88	8.73	18.6	0.12	8.05	0.68	8328	7.8	388.9
HL08	4308	87	2.0	65.6	38.15	1.95	5.1	0.16	0.96	0.99	15061	50.8	35.3
HL09	4096	120	2.9	126.8	34.18	8.33	24.4	0.44	4.38	3.95	31178	47.4	138.3
HL10	85	85	100.0	32.5	0.33	0.33	100.0	0.17	0.13	0.21	6365	62.2	6.5
HL11	141	64	45.0	27.9	0.45	0.19	41.1	0.05	0.09	0.10	3555	53.2	5.6
HL12	78	78	100.0	34.0	0.27	0.27	100.0	0.11	0.12	0.15	4295	54.7	5.8
HL13	68	68	100.0	30.6	0.34	0.34	100.0	0.18	0.10	0.25	8020	72.1	5.0
HL14	3915	84	2.1	82.0	20.02	0.00	0.0	0.14	-1.03	-0.77	-9350	42.7	-42.1
HL15	310	88	28.3	44.3	0.93	0.19	20.6	0.12	0.07	0.13	2822	65.4	2.6
HL16	222	132	59.5	60.2	0.74	0.15	20.3	0.19	0.01	0.14	2278	91.9	0.3
HL17	90	90	100.0	39.5	0.59	0.59	100.0	0.16	0.23	0.36	8992	60.5	9.4
HL18	3540	125	3.5	98.7	20.89	0.58	2.8	0.23	1.10	-0.58	-5826	-108.7	28.0
HL19	3416	54	1.6	38.0	20.37	1.22	6.0	0.12	3.08	-1.87	-49132	-153.6	229.8
HL20	704	119	16.8	52.4	2.44	0.88	35.9	0.23	0.54	0.34	6392	38.2	20.3
HL21	585	132	22.6	47.9	1.57	0.42	26.7	0.24	0.18	0.24	4995	57.0	6.5
HL22	453	140	30.8	63.3	1.15	0.39	33.9	0.28	0.19	0.20	3221	52.3	5.7
HL23	92	92	100.0	37.0	0.26	0.26	100.0	0.19	0.13	0.13	3514	50.2	5.6
HL24	222	222	100.0	63.1	0.50	0.50	100.0	0.31	0.18	0.32	5006	63.2	4.9
HL25	2545	172	6.8	72.8	4.94	0.44	9.0	0.30	0.82	-0.46	-6308	-125.8	22.0
HL26	2372	221	9.3	71.3	4.58	0.00	0.0	0.30	-0.60	-1.91	-26782	76.2	-16.1
HL27	147	147	100.0	59.0	0.51	0.51	100.0	0.26	0.21	0.29	4949	57.8	5.9
HL28	2004	235	11.7	57.1	6.58	6.02	91.5	0.15	2.81	3.21	56235	53.3	101.9

Basin	A_{gross} (acres)	A_{net} (acres)	A_{net}/A_{gross} (%)	IDM (in-dia-mile)	ADF_{gross} Ave. Daily Flow (MGD)	ADF_{net} Ave. Daily Flow (MGD)	Q_{net}/Q_{gross} (%)	Water Consumption (MGD)	Wastewater Production WWP (MGD)	Base Infiltration BI_{net} (MGD)	Base Infiltration (BI) Severity (gpd/idm)	Base Infiltration (BI) Rate (%)	Wastewater Production (WWP) Rate (gal/l.f.)
HL29	200	200	100.0	41.4	0.15	0.15	100.0	0.10	0.07	0.08	1885	52.3	3.1
HL30	139	139	100.0	51.1	0.41	0.41	100.0	0.19	0.07	0.34	6579	82.4	2.2
HL31	1430	176	12.3	53.6	0.00	0.00	0.0	0.14	0.00	0.00	0	0.0	0.0
HL32	249	116	46.7	32.4	0.31	0.05	14.7	0.09	0.03	0.01	432	29.8	1.6
HL33	132	132	100.0	32.1	0.27	0.27	100.0	0.10	0.06	0.21	6476	78.2	2.8
HL34	1006	76	7.5	27.1	2.39	0.00	0.0	0.11	0.42	-0.78	-28714	214.6	26.8
HL35	930	161	17.4	61.0	2.75	0.39	14.1	0.20	0.05	0.34	5594	88.3	1.3
HL36	244	65	26.5	19.9	0.70	0.43	61.8	0.07	0.18	0.26	12915	59.5	14.7
HL37	179	179	100.0	44.3	0.27	0.27	100.0	0.18	0.09	0.18	3951	65.5	3.2
HL38	525	133	25.2	36.2	1.67	0.93	55.9	0.16	0.20	0.73	20133	78.1	9.4
HL39	392	123	31.4	48.5	0.74	0.06	8.6	0.16	0.04	0.03	578	43.8	1.3
HL40	160	160	100.0	33.7	0.33	0.33	100.0	0.17	0.11	0.23	6712	68.1	4.9
HL41	109	109	100.0	35.4	0.34	0.34	100.0	0.11	0.13	0.21	5989	62.2	6.2
TSHL	3249	113	3.5	40.0	7.60	0.00	0.0	0.08	-13.41	-1.29	-32284	8.8	-744.5

* Cells were grayed out when WWP or BI is negative; WWP Rate exceeds 35 (gal/l.f.); WWP is less than 50% of water consumption; or Anet/Agross is less than 20%

Table 3-2B Modified Dry Weather Analysis DST - Winter 2007 - Weekdays Only													
Basin	A_{gross} (acres)	A_{net} (acres)	A_{net}/A_{gross} (%)	IDM (in-dia-mile)	ADF_{gross} (MGD)	ADF_{net} (MGD)	Q_{net}/Q_{gross} (%)	Water Consumption(MGD)	WWP (MGD)	BI_{net} (MGD)	BI Severity**** (gpd/idm)	BI Rate (%)	WWP Rate (gal/l.f.)
HL06	94	94	100.0	46.0	0.43	0.43	100	0.15	0.13	0.30	6,564	70.2	4.7
HL10	85	85	100.0	32.5	0.33	0.33	100	0.17	0.13	0.21	6,365	62.2	6.5
HL11	141	64	45.0	27.9	0.45	0.19	41	0.05	0.09	0.10	3,555	53.2	5.6
HL12	78	78	100.0	34.0	0.27	0.27	100	0.11	0.12	0.15	4,295	54.7	5.8
HL13	68	68	100.0	30.6	0.34	0.34	100	0.18	0.10	0.25	8,020	72.1	5.0
HL15-16	532	220	87.8	104.5	0.93	0.34	37	0.32	***0.27***	***0.07***	***623***	***19.1***	***4.5***
HL17	90	90	100.0	39.5	0.59	0.59	100	0.16	0.23	0.36	8,992	60.5	9.4
HL20	704	119	16.8	52.4	2.44	0.88	36	0.23	0.54	0.34	6,392	38.2	20.3
HL21	585	132	22.6	47.9	1.57	0.42	27	0.24	0.18	0.24	4,995	57.0	6.5
HL22	453	140	30.8	63.3	1.15	0.39	34	0.28	0.19	0.20	3,221	52.3	5.7
HL23	92	92	100.0	37.0	0.26	0.26	100	0.19	0.13	0.13	3,514	50.2	5.6
HL24	222	222	100.0	63.1	0.50	0.50	100	0.31	0.18	0.32	5,006	63.2	4.9
HL27	147	147	100.0	59.0	0.51	0.51	100	0.26	0.21	0.29	4,949	57.8	5.9
HL29	200	200	100.0	41.4	0.15	0.15	100	0.10	0.07	0.08	1,885	52.3	3.1
HL30	139	139	100.0	51.1	0.41	0.41	100	0.19	0.16	0.25	4,817	60.3	4.9
HL32-33	381	249	146.7	64.6	0.31	0.31	100	0.20	***0.17***	***0.14***	***2,196***	***45.4***	***4.1***
HL34-35	1935	237	24.9	88.1	2.39	0.39	16	0.31	***0.27***	***0.12***	***1,318***	***29.9***	***5.4***
HL36	244	65	26.5	19.9	0.70	0.43	62	0.07	0.18	0.26	12,915	59.5	14.7
HL37	179	179	100.0	44.3	0.27	0.27	100	0.18	0.09	0.18	3,951	65.5	3.2
HL38-39	917	255	56.6	84.6	1.67	1.00	60	0.32	0.24	0.76	8,920	75.9	4.8
HL40	160	160	100.0	33.7	0.33	0.33	100	0.17	0.11	0.23	6,712	68.1	4.9
HL41	109	109	100.0	35.4	0.34	0.34	100	0.11	0.13	0.21	5,989	62.2	6.2
Lower GRI**	3249	917	28.2	295	8.70	1.65	19	0.97	***0.84***	***0.69***	***2,329***	***44.9***	***5.7***
HLI***	4518	551	12.2	493	46.77	2.82	6	1.21	***1.05***	***1.61***	***3,273***	***60.6***	***6.7***

* Sites that were combined and represented as one basin due to flow imbalance issue in the upstream basin are represented in red and italic font.

** Water consumption rate was used for WWP when WWP from Sliicer is less than 50% of the water consumption

*** Lower GRI basins consist of HL25, 26, 28, 31, and TSHL03

**** HLI basins consist of HL07, 08, 09, 14, 18 and 19

***** BI Severity for Lower GRI basins was calculated based on Summer 2006 results

3.4 WET WEATHER ANALYSIS

3.4.1 Global Storms

A total of 29 storms during the metering period met the criteria for a storm event as defined by the global settings (see Table 2-2). Each storm was analyzed for each flow meter using the Sliicer.com software.

3.4.2 Pre-Composition Period

For each storm, a pre-composition period (typically 24 hours prior to the storm event) was established to adjust the dry day hydrograph to match the actual hydrograph immediately prior to the start of a storm event. This either raises or lowers the dry day hydrograph so that the calculated rainfall-dependent infiltration and inflow (RDII) is a result of only this storm event.

3.4.3 Storm Measurement Periods

Sliicer.com calculates I&I components for three periods following the start of a storm event. These are called Storm, Recovery 1 and Recovery 2. Each period, by default, was 24 hours long based on the global settings. For this project, however, the storm periods were set by the City, are specific for each storm, and are long enough to capture all the RDII behavior. The recovery periods 1 and 2 were set to 60 minutes, but were not used in any calculations.

3.4.4 RDII Calculations

In order to estimate the RDII, Sliicer superimposes the typical dry-day hydrograph on a storm hydrograph. The difference between two hydrographs represents the RDII pattern.

3.4.5 RDII Normalization

3.4.5.1 By Linear Footage

Normalizing the RDII is extremely important when comparing results to determine the worst basins for immediate I&I control. A simple interpretation of most raw wet weather flow does not always lead to right conclusions about the locations of worst I&I problems in a collection system. Although the raw I&I information is part of the picture, it needs to be correlated with basin size and rainfall information before it can be used. For this project, the RDII was normalized based on linear footage (gal/l.f./in-of-rain). The Sliicer provides this type of normalization for each meter for each storm. The average of all storms was calculated.

3.4.5.2 By Area (Capture Coefficient)

A graphical technique for evaluating and comparing the performance of sewershed basins under widely varying rain events is the Q versus I diagram. "Q" is the calculated I&I flow rate for a storm and "I" is the corresponding rainfall. The slope (S) of regression line on the Q vs. I plot was used in the following equation to obtain the capture coefficient (R). A capture coefficient represents the percentage of the volume of rain water that falls on a basin and finds its way into the collection system.

$$R = (36.83_{\text{(acres-in/mg)}} * S_{\text{(mg/in)}}) / \text{Area}_{\text{(acres)}}$$

There were difficulties in determining the RDII rates for some flow basins in HLSS including the interceptor basins where the net basin area was less than 20% of the gross area. The basin aggregation process similar to the dry weather flow was attempted, but did not turn out to be successful for the interceptor basins due to highly varying boundary flows from the Ashburton WFP and significant amount of wet weather flows from other sewersheds. HL31 and its downstream basins along GRI and HLI had to be excluded from the RDII evaluation. Flow imbalance issues existed even after the interceptor flows were excluded and, consequently, the HLSS team resolved the RDII flow imbalance issues primarily using the Sliicer-calculated gross RDII values instead of the net values. The RDII imbalance resolution process is described in Section 4.4.2 of the HLSS Model Development and Calibration Report. Table 3-3 shows the results of the wet weather analysis and Figure 3-2 shows the year-round RDII severity in the HLSS.

3.5 SMOKE TESTING DATA ANALYSIS

As of February 2009, about 200,000 linear feet of sewer in HLSS had been smoke tested. The smoke tested areas included HL27, 30, 31, 32, 33, 34, 35, 36, and 40, all of which were flow basins contributing to the Gwynn's Run Interceptor. These data are currently undergoing QA/QC and an additional 90,000 linear feet of sewers will be smoke tested in Spring 2009. The HLSS team summarized the current smoke testing data for each flow basin and utilized it to support the dry and wet weather analysis.

Table 3-4 summarizes the number count of each smoke testing defect for each flow basin. Many cleanouts were defective although this type of defect would usually be a minor contributor of RDII. In many cases, the uncapped or loose-capped cleanouts protrude above the ground and no water from a small, localized catchment can flow into the cleanout. Typically, the only inflow caused by a defective cleanout is the rain that directly falls on the cleanout opening. This table shows the total number of non-cleanout defects and the same count normalized by smoke tested length. The total number of non-cleanout defect sources per 10,000 ft is 13 for HL32, 5 for HL33 and 35, while the other flow basins had equal or less than three non-cleanout defect sources per 10,000 ft (Table 3-5). It should be noted that some of the catch basin defects in HL33 and 31 were due to storm and sanitary cross connection through remaining engineered overflows.

Table 3-3 Wet Weather Analysis								
Meter	**Year-round RDII Severity (gal/l.f.-in)**	**Year-round Capture Coefficient R (%)**	**Winter Capture Coefficient R (%)**		**Meter**	**Year-round RDII Severity Ranking**	**Winter Capture Coefficient R Ranking**	**Year-round Capture Coefficient R Ranking**
HL06	11.7	7.2	12.5		HL36	1	1	2
HL07	N/A	N/A	N/A		HL37	2	3	4
HL08	N/A	N/A	N/A		HL32	3	2	1
HL09	N/A	N/A	N/A		HL33	4	6	5
HL10	6.7	3.9	5.6		HL39	5	4	6
HL11	10.3	8.4	9.3		HL40	6	9	9
HL12	3.3	2.1	3.3		HL38	7	10	7
HL13	5.2	5.4	5.4		HL23	8	5	3
HL14	N/A	N/A	N/A		HL27	9	7	8
HL15	5.4	5.2	5.7		HL41	10	12	12
HL16	4.7	3.0	4.7		HL06	11	8	11
HL17	8.5	6.1	8.6		HL11	12	11	10
HL18	N/A	N/A	N/A		HL22	13	14	15
HL19	N/A	N/A	N/A		HL21	14	16	14
HL20	8.7	5.3	7.2		HL20	15	15	18
HL21	9.3	5.7	7.2		HL17	16	13	13
HL22	9.8	5.5	8.4		HL24	17	22	21
HL23	15.5	11.3	14.5		HL29	18	25	24
HL24	8.3	4.2	5.1		HL34	19	18	17
HL25	N/A	N/A	N/A		HL35	20	19	19
HL26	N/A	N/A	N/A		HL10	21	20	22
HL27	13.9	8.7	12.5		HL15	22	17	20
HL28	N/A	N/A	N/A		HL13	23	21	16
HL29	7.8	2.4	3.3		HL16	24	23	23
HL30	1.5	0.9	1.3		HL12	25	24	25
HL31	N/A	N/A	N/A		HL30	26	26	26
HL32	24.9	12.3	16.4		HL07	N/A	N/A	N/A
HL33	23.8	10.7	13.6		HL08	N/A	N/A	N/A
HL34	7.5	5.3	5.7		HL09	N/A	N/A	N/A
HL35	7.2	5.2	5.7		HL14	N/A	N/A	N/A
HL36	28.1	11.9	19.1		HL18	N/A	N/A	N/A
HL37	26.5	11.1	15.6		HL19	N/A	N/A	N/A
HL38	16.3	9.3	9.8		HL25	N/A	N/A	N/A
HL39	17.6	10.3	15.0		HL26	N/A	N/A	N/A
HL40	16.6	8.5	12.1		HL28	N/A	N/A	N/A
HL41	12.9	6.6	9.1		HL31	N/A	N/A	N/A
TSHL03	N/A	N/A	N/A		TSHL03	N/A	N/A	N/A
* Grey cells are sites where capture coefficient was not able to be calculated because of flow imbalance issues								

Table 3-4 Summary of smoke testing defect sources												
Flow Basin	Catch Basin	Service Line	Main Sewer	MH Frame	Cleanout	Down spout	Area/Driveway /Stairwell Drain	Other	Total	Total (Not cleanout)	Length Tested	Non-Cleanout defect counts per 10,000 ft
HL27	2	2		1	33	1	1	3	43	10	34,469	3
HL30	4	1			76			1	82	6	30,247	2
HL31*	2	1	1	1	42			1	48	6	23,552	3
HL32	7	15	2		84	1	1	1	111	27	20,457	13
HL33	5	3			32	1	1		42	10	20,404	5
HL34		1		1	43				45	2	15,491	1
HL35	10	3			65	1	2	1	82	17	36,021	5
HL36		1			33				34	1	11,504	1
HL40		7			46				53	7	20,482	3
Total	30	34	3	3	454	4	5	7	540	86	212,627	36

* West side of rail road only

Table 3-5 Smoke testing defect source counts	
Number of non-cleanout defect sources per 10,000 ft	Flow basin
1-3	HL27, 30, 31, 34, 36, 40
5	HL33, 35
13	HL32

3.6 RELINED PIPES

In HLSS, two large relining projects were recently completed: SC807 and SC831. Very little infiltration could be expected from these relined pipes since both projects were conducted between 2002 and 2005. The total relined length of each project is summarized in Table 3-6. The relined sewers were essentially limited to the upper portion of GRI.

Table 3-6 Relined Pipe length by SC807 and SC831

Basin	SC807 (ft)	SC831 (ft)	Total Relined length (ft)	Total Sewer Length (ft)	Percent Relined (%)
HL31	3,218	0	3,218	28,429	11.3
HL32	3,178	0	3,178	20,760	15.3
HL33	44	0	44	20,618	0.2
HL34	1,671	0	1,671	15,510	10.8
HL35	3,598	0	3,598	34,548	10.4
HL36	1,467	0	1,467	11,926	12.3
HL37	889	4,481	5,369	28,660	18.7
HL38	2,061	0	2,061	21,666	9.5
HL39	2,761	1,287	4,048	28,375	14.3
HL40	0	2,308	2,308	21,717	10.6
HL41	2,973	2,802	5,776	20,924	27.6

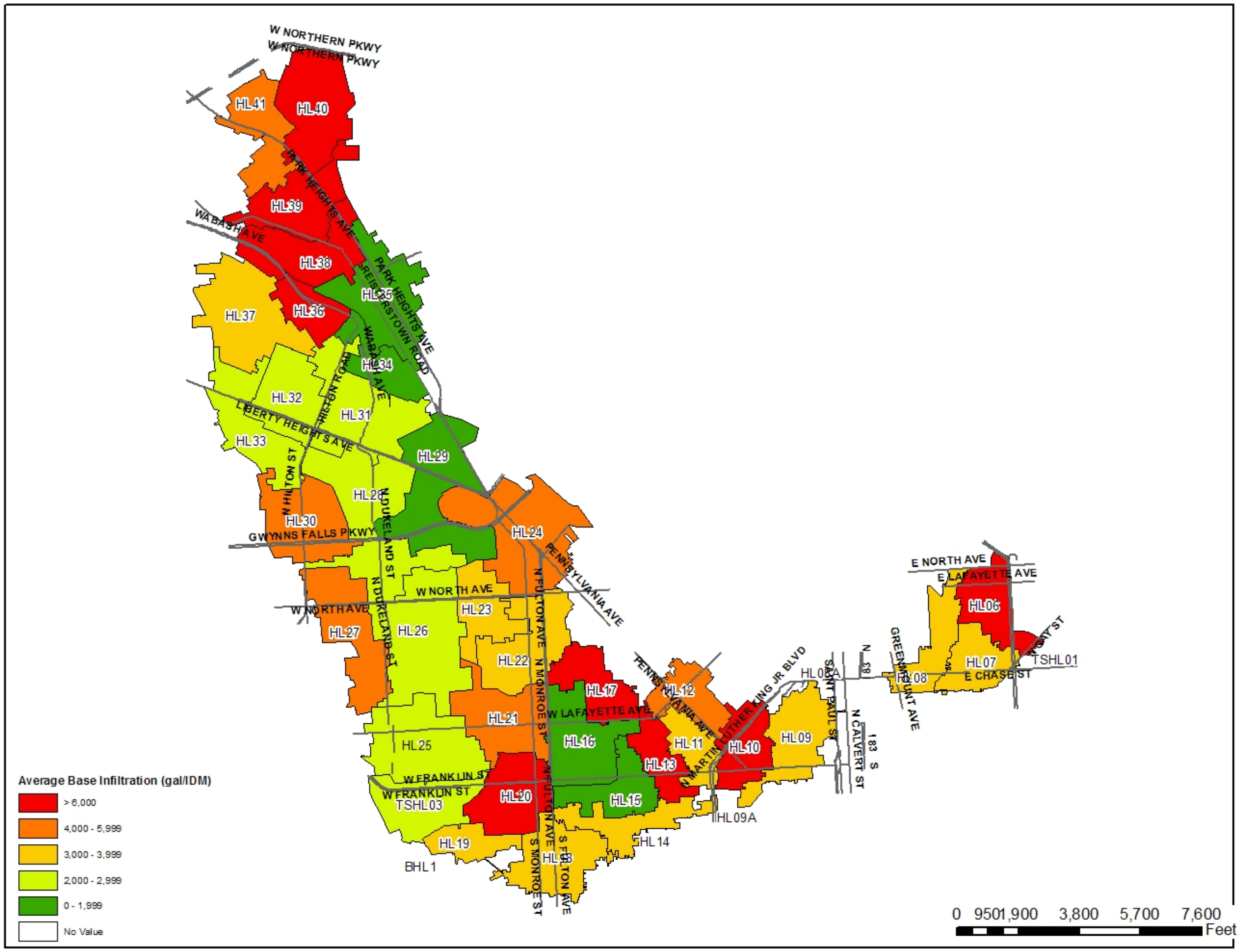

Figure 3-1 Winter Base Infiltration in HLSS

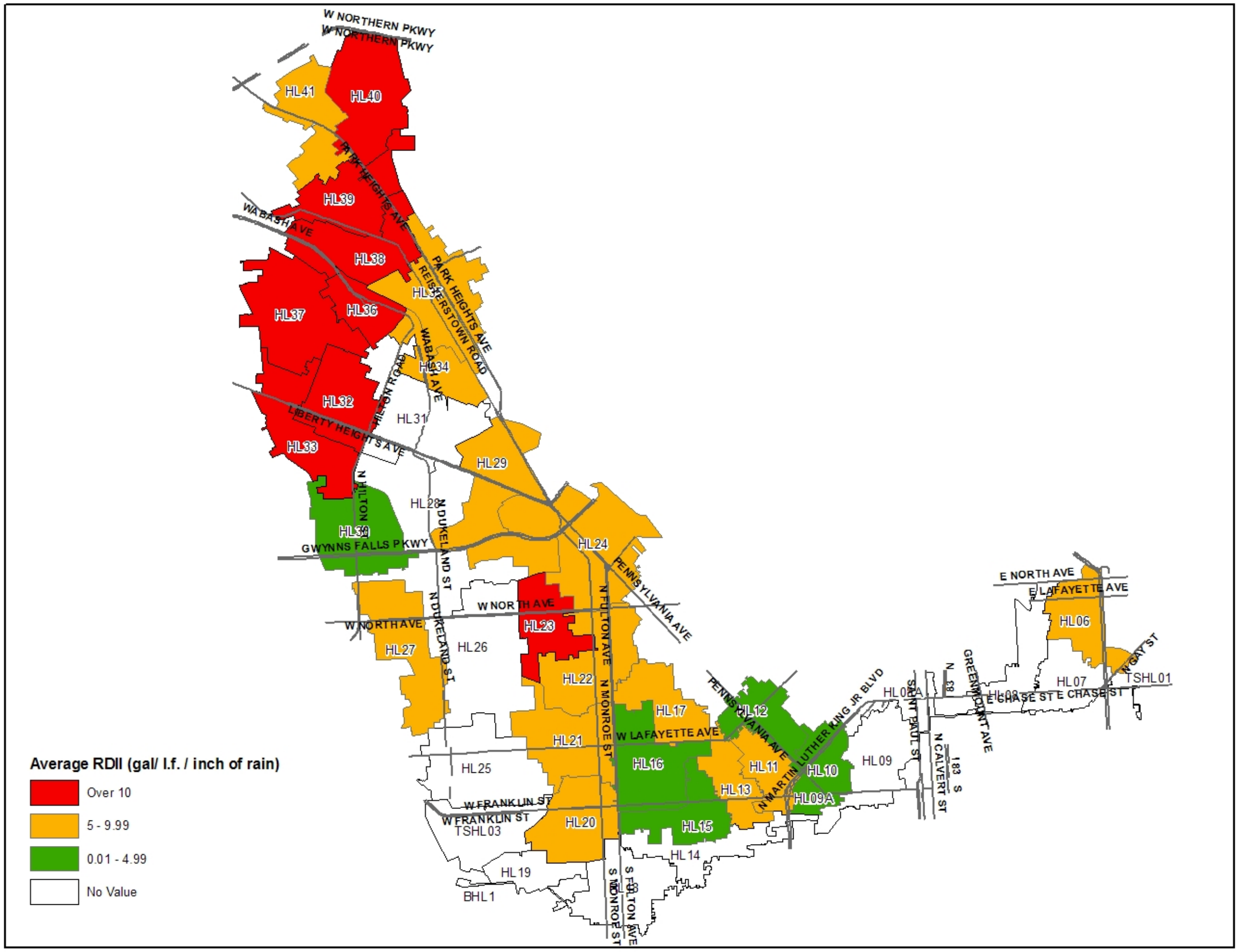

Figure 3-2 Year-round RDII severity in HLSS

SECTION 4

EVALUATION OF RESULTS

4.1 DRY DAY RESULTS

The dry day results are shown in Table 3-2-B and Figure 3-1, in terms of the BI values normalized by IDM. For HL31 and its downstream basins along the GRI and HLI, the BI could not be determined due to flow imbalance issues and large inflows from upstream, boundary and Ashburton water filtration plant. Among the remaining 26 basins, the normalized BI exceeded 4,000 gal/IDM for 15 flow metering basins and exceeded 6,000 gal/IDM for nine basins among them.

For the upper GRI basins which contribute to GRI upstream of the SC812 and subsequently connect to the 30-inch SC812 relief pipe (HL31-41), BI rate exceeded 4,000 gal/IDM for five basins (HL36, 38, 39, 40, and 41). For basins that connect to the existing lower GRI from the upstream end of SC812 to the HLI (HL25-30 and TSHL03), the BI rate exceeded 4,000 gal/IDM for only two basins (HL27 and 30). However, it should be noted that the BI rate was not calculated for the interceptor basins (HL25-28 and TSHL03). For the secondary GRI basins (HL20-24), the BI rate exceeded 3,000 gal/IDM for all basins, and was in excess of 4,000 gal/IDM for three out of these five basins.

For the HLI basins (HL07-09, 14, 18, and 19), it was difficult to separate the BI rate due to a large amount of interceptor flow in comparison to a relatively small amount of BI. For minor tributary basins contributing to the HLI (HL06, HL10-13, and HL15-17), the BI rate exceeded 4,000 gal/IDM for five out of the eight basins.

4.2 WET WEATHER RESULTS

The RDII severity in the HLSS, normalized by pipe length and rainfall (Figure 3-2), exhibited several regional patterns. The average RDII exceeded 10 (gal/l.f./inch of rain) for most basins contributing to the upper GRI, north of Ashburton WFP (HL31-41). The remaining basins (except HL 30 and some minor flow basins contributing to the HLI including: HL10, 12, 15, and 16) the average RDII was between 5 and 10 gal/l.f./inch of rain.

Smoke testing results were also reviewed as a part of wet weather analysis. The number of non-cleanout smoke testing defects per 10, 000 ft was counted for each flow basin. The number of non-cleanout defects per 10,000 ft in HL32 was much larger than other smoke-tested basins. It correlated well with RDII severity results for HL32, which had the worst year-round capture coefficient in the HLSS.

The scattergraph plots included in the attached CD showed the evidence of possible sanitary sewer overflows (SSOs) at some locations along the GRI and HLI. Table 4-2 summarizes the maximum surcharge depths and potential SSO occurrences around each flow meter.

The flow meter manholes at HLI, HL07, HL09, and, to a lesser extent, HL18 were among the locations where the maximum surcharge was at or above the manhole rim elevation. This indicated that there had been at least one SSO event at these flow meter manholes. A known HLI manhole periodically overflows in front of the Baltimore City Detention Center (BCDC). It is not very clear in the HL08A scattergraph that a SSO ever occurred at the BCDC, which is located approximately 1,000 feet upstream of the HL08A flow meter. However, visual observations and resident complaints confirmed the occurrence of overflows. The Alternatives Analysis report currently being prepared by the HLSS team will discuss the SSO occurrence near BCDC and will make recommendations to prevent further overflows around this location.

Along GRI, the maximum surcharge depth exceeded the manhole depth at HL38. The scattergraph for HL31 exhibited an evidence of recurring SSOs at or near 2800 Dukeland Street. The scattergraph of extended flow monitoring data available at HL31 suggested that the 2800 Dukeland Street SSO no longer existed. The new relief sewer constructed as part of SC 812 eliminated the potential for high surcharging or overflow at this location.

Several engineered overflows were recently abandoned and permanently plugged along the GRI. These included five engineered overflows (55, 56, 57, 130, and 131) along GRI in the vicinity of the upstream end of SC 812, and two engineered overflows (106 and 107) near the downstream end of GRI. Additional overflows could occur along GRI since these engineered overflows, which relieved flows from sanitary to storm sewers, no longer exist.

The scattergraphs at HL32 and 33 exhibited an evidence of overflow through the remaining, active engineered overflows 132, 134, and 135. Recommendations intended to eliminate these overflows will be further developed in the HLSS Alternative Analysis report. This area is called Liberty Heights area for which a separate analysis and report was submitted by the HLSS team to the City.

Table 4-1 Scattergraph Review Summary								
Meter	**Manhole Depth (ft)**	**Manhole Depth (in)**	**Pipe height (in)**	**Maximum surcharge depth (in)**	**Ever Surcharged during monitoring period?**	**Maximum Surcharge Depth greater than MH depth?**	**SSO Evidence from Scattergraph?**	**Note**
HL06	10.74	128.9	20	100	Yes			
HL07	11.3	135.6	100	160	Yes	Yes	Yes	SSO might have occurred at this manhole
HL08	40.4	484.8	95	165	Yes			
HL08A	22.5	270.0	95	170	Yes		Not clear	SSOs have repeatedly occurred at the downstream end of the HLI siphon approximately 1,000 ft upstream of HL08A with severe storms
HL09	10.5	126.0	82.5	130	Yes	Yes	Not clear	SSO might have occurred at this manhole
HL09A	16.98	203.8	69	115	Yes			
HL10	13.55	162.6	18	21	Yes			
HL11	16.34	196.1	18	114	Yes			
HL12	13.24	158.9	18	7				
HL13	10.46	125.5	15	56	Yes			
HL14	15.31	183.7	57	170	Yes			
HL15	13.28	159.4	24	55	Yes			
HL16	18.17	218.0	20	76	Yes			
HL17	15.29	183.5	15	6				
HL18	13.21	158.5	53	157	Yes		Not Clear	Maximum surcharge depth is very close to the manhole depth
HL19	54.99	659.9	52	112	Yes			
HL20	11.9	142.8	27	57	Yes			
HL21	11.31	135.7	27	25				
HL22	13.75	165.0	33	25				
HL23	10.05	120.6	15	15.5	Yes			
HL24	18.11	217.3	18	14.5				
HL25	19.03	228.4	33	75	Yes			

Table 4-1 Scattergraph Review Summary								
Meter	**Manhole Depth (ft)**	**Manhole Depth (in)**	**Pipe height (in)**	**Maximum surcharge depth (in)**	**Ever Surcharged during monitoring period?**	**Maximum Surcharge Depth greater than MH depth?**	**SSO Evidence from Scattergraph?**	**Note**
HL26	34.1	409.2	39	100	Yes			
HL27	11.11	133.3	15	62	Yes			
HL28	17.03	204.4	22	84	Yes			
HL29	25.54	306.5	18	7				
HL30	7.13	85.6	10	16.5	Yes			
HL31	12.28	147.4	24	140	Yes		Yes	SSO occurred at 2800 Dukeland St. before SC812 was installed
HL32	9.7	116.4	12	27	Yes		Not clear	SSO through the remaining engineered overflow 134
HL33	13.81	165.7	12	125	Yes		Yes	SSO through the remaining engineered overflow 132
HL34	23.1	277.2	21	130	Yes			
HL35	25.8	309.6	21.25	140	Yes			
HL36	13.47	161.6	14	35	Yes			
HL37	14.03	168.4	14	55	Yes			
HL38	9.9	118.8	14	150	Yes	Yes	Yes	SSO might have occurred at this manhole
HL39	14.78	177.4	18	94	Yes			
HL40	12.8	153.6	12	92	Yes		Yes	SSO through the remaining engineered overflow 55.
HL41	11.44	137.3	14	72	Yes			
TSHL03	13.8	165.6	37	70	Yes			
TSHL01	18.2	218.4	129	175	Yes			